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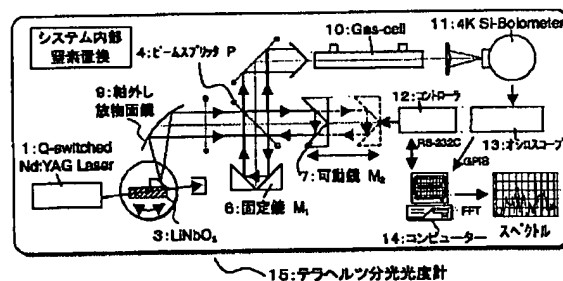
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(54) 【発明の名称】 テラヘルツ分光光度計

(57) 【要約】

【課題】 強いスペクトル強度をもつ波長可変テラヘルツ波光源と、二光束干渉を用いたマーチンパレット型フーリエ干渉計を組み合わせることにより、THz領域での分光を、S/N良く測定できる分光光度計を提供する。

【解決手段】 非線形結晶 LiNbO_3 を Nd:YAG レーザー1で励起することにより発生したTHz波を Si プリズム2を用い空間に放射し軸外し放物面鏡9によりコリメートするTPG光源と、このTHz波をビームスプリッター4により二光束に分割した後、固定鏡 M_1 6と可動鏡 M_2 7により再び重ねられ干渉させるMP型干渉計、また分光の為に資料が充填されたガスセル10やTHz波を検出する為の4K-Siボロメータ11等、これらを具備したテラヘルツ分光計15を構成した。



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【特許請求の範囲】

【請求項1】 非線形光学効果であるパラメトリック発生(PG)により得られる波長可変テラヘルツ波(以下テラヘルツパラメトリック発生:TPGと省略)を光源として用いることを特徴とする分光計。

【請求項2】 請求項1において、非線形結晶として LiNbO_3 や LiTaO_3 等を用い、近赤外の光源で励起することにより発生するテラヘルツ(以下THzと省略)波を小型かつ強力な遠赤外領域での光源とすることを特徴とする分光計。

【請求項3】 請求項2において、非線形結晶内より生ずるTHz波の中心波長を、前記励起光源の結晶への入射角度を変化させることにより可変させることが可能な光源をもつことを特徴とする分光計。

【請求項4】 請求項2において、非線形結晶からのTHz波の大気中への取り出しに、Si製のプリズムを用いることにより、励起光源の結晶への入射角度を変えてもほぼ一方にTHz波が射出される特徴を持つ光源をもつことを特徴とする分光計。

【請求項5】 強いスペクトル強度をもつ波長可変TPG光源と、二光束干渉を用いた分光器を組み合わせることを特徴とする小型高輝度テラヘルツ分光光度計。

【請求項6】 請求項5において、干渉計にサブミリ波領域での効率の良い透過特性を持つワイヤーグリッドをビームスプリッターに用いたマーチン-パレット型フーリエ干渉計(以下MP型干渉計と省略)を用いる分光計。

【発明の詳細な説明】

【0001】

【発明の所属する技術分野】本発明は、非線形光学効果であるパラメトリック発生により得られる強いスペクトル強度をもつ波長可変TPG光源と、二光束干渉を用いた分光器を組み合わせることにより実現される、小型高輝度テラヘルツ分光光度計に関するものである。

【0002】

【従来の技術】遠赤外領域の分光には、従来、連続的な周波数成分を持つ高圧水銀灯がほとんど唯一の光源として用いられており、分光計としては光量の有効利用の点で有利な、二光束干渉を用いたフーリエ変換分光計(以下FTSと省略)が広く用いられている。これは干渉光強度が光源スペクトルの波数空間から実空間へのフーリエ変換に対応していることを利用したものである。FTSでは、光源から光をビームスプリッターにより二光束に分け、二光束間に光路差を作り出した後干渉させ、その干渉曲線からスペクトルを得ているが、その二光束を得る方法により、FTS種類は、振幅分割により二光束を得るマイケルソン型、波面分割により二光束を得るラメラー型、および偏光を利用して二光束を得るマーチン-パレット型の3種に大別される。この中でサブミリ領域マイケルソン型FTSの半透明鏡の効率が落ちる

為、効率の良い透過特性を持つMP型干渉計が多く利用されている。

【0003】

【発明が解決しようとする課題】従来の遠赤外分光では、光源である高圧水銀灯のスペクトル強度が低いため、インターフェログラム情報がノイズを多く含み、全体的なS/N比が低下してしまうという欠点がある。このTHz領域(0.5~5THz)での分光を、S/N良く測定できることを目的とする。

10 【0004】

【課題を解決する為の手段】上記課題を解決する為に、本発明は、次のようなテラヘルツ分光光度計を採用した。即ち、請求項1記載の、パラメトリック発生により得られる波長可変TPGを光源として用い、それを請求項5にあるように、二光束干渉を用いた分光器と組み合わせることにより実現される、小型高輝度テラヘルツ分光光度計である。光源は、請求項2記載の非線形結晶 LiNbO_3 や LiTaO_3 等を近赤外の光源で励起することにより発生するTPGを用いた。これは、広い遠赤外領域で波長可変でありnsec幅のパルスであるために比較的強い強度と長い光路長、ブロードなスペクトル特性を持つことから、分光に有利な特徴を有しており、小型かつ強力な遠赤外領域での光源となり得る。更に分光の方式としては、遠赤外領域での光量の有効利用を考えると二光束干渉を用いたフーリエ分光計が望ましく、中でもとくにサブミリ波領域での効率の良い透過特性を持つ請求項6記載のMP型干渉計の構成を用いた。

【0005】

【発明の実施の形態】以下、図面を参照して、本発明の形態について説明する。この発明は、請求項5に記載してあるように、波長可変TPG光源と、MP型干渉計を組み合わせることで実現される小型高輝度テラヘルツ分光光度計である。ここで、それぞれの原理を示す。

A. THz波パラメトリック発生(TPG)の発生原理
光パラメトリック相互作用においては、ポンプ波

(ω_P) ω_P を請求項2記載の非線形光学結晶に入射するとシグナル波(ω_T)およびアイドラー波(ω_i)がエネルギー保存則 $\omega_P = \omega_T + \omega_i$ に従って発生する現象であり、シグナル波 ω_T の周波数をTHz波帯にまで拡張することにより、分光に適した幅広いスペクトルを持つ光源を提供することが可能となる。請求項1記載のパラメトリック相互作用を用いた光波の波長変換によってTHz波発生を行なうとき、純粋な光波だけの相互作用を用いた場合には利得が小さく、THz波帯の動作が困難である。しかし、前記 LiNbO_3 や LiTaO_3 などラン活性かつ赤外光活性な該非線形光学材料を用いると、物質の素励起波(ボラリトン)を介して強い相互作用を起こすことができる。図1に示すようにボラリトンは低エネルギー領域ではフォトンの振舞いするため、請求項2記載の十分強い励起光源を用いれば、ボラリトンを

介した誘導散乱現象を引き起こし高効率なTHz波(ω_T)発生が可能である。図2にTPG実験の概要図を示す。結晶内にポンプ光を入射したとき入射端で発生した量子雑音(熱雑音)が結晶利得により増幅され、ポンプ光から周波数がシフトした光(アイドラ光)が出力される。そしてポンプ光とアイドラ光がエネルギー保存則($\omega_P = \omega_i + \omega_T$)と運動量保存則($k_P = k_i + k_T$)を満たしたところでTHz波が発生する。発生するTHz波は受光角に依存した幅広いスペクトル(約15 cm⁻¹)を持ち、結晶の入射角を変化させることにより中心波長を同調できる。図3はノンドープLiNbO₃結晶を波長1.064 μmにより励起した場合の利得の計算結果であり、150~400 μm程度の領域に高い利得をもつことがわかる。ポンプ光強度 I_P とともに利得係数が増大する特性は、利得が I_P の平方根に比例すること起因している。また、低温領域において利得係数が増大する特性は、主としてTHz波帯での吸収係数の減少に起因している。

B. マーチンパレット型干渉計の原理

請求項6記載のMP型干渉計の構成を図4に示す。前記MP型干渉計では入射光の偏光方向を分割して二つの光束をつくる偏光分割方式を用いる。請求項6記載のワイヤグリッドは、その該ワイヤに対して平行な偏光方向の電磁波を反射し、垂直な電磁波を透過させる(図5)。つまり、電磁波の偏光方向に対して前記ワイヤグリッドを45°に傾けることにより入射電磁波の反射・透過を1:1にすることが可能であり、効率のよい電磁波の分割が出来るという特徴を持つ。入射するTHz波の偏光方向は紙面と垂直である。45°においた前記ワイヤグリッドの請求項6記載のビームスプリッタDによりTHz波は1:1に分けられる。反射光と透過光はそれぞれ固定鏡と可動鏡により反射されて、偏光方向が90°回転される。再びDで結合したTHz波はポラライザP(ワイヤグリッド)によって該ワイヤに平行な成分と垂直な成分に分けられる。前記ビームスプリッタに入射する電界は、

$$E_i = e_i \frac{a}{\sqrt{2}} \cos \omega t + e_i \frac{a}{\sqrt{2}} \cos \omega t \quad \dots (1)$$

再び前記ビームスプリッタで結合した電界は

$$E_j = e_i \frac{a}{\sqrt{2}} \cos(\omega t + \Delta_A) + e_i \frac{a}{\sqrt{2}} \cos(\omega t + \Delta_B) \quad \dots (2)$$

となり、前記ポラライザPから出射するとその振幅は次のようになる。

$$|E| = \frac{a}{2} (\cos(\omega t + \Delta_A) - \cos(\omega t + \Delta_B)) \quad \dots (3)$$

ただし、 Δ_A 、 Δ_B はそれぞれの位相変化であり、その強度は

【数式4】

$$I_P = \langle |E|^2 \rangle = \frac{a^2}{4} (1 - \cos \Delta) = \frac{I_0}{2} (1 - \cos \Delta) \quad \dots (4)$$

となる。ここで $\Delta = 2\pi \sigma x$ 、 x は光路差、 σ は波数である。そのスペクトル強度を $B(\sigma)$ とすると、すべての σ について積分することにより、全強度は

【数式5】

$$I(x) = \frac{1}{2} \int_0^\infty B(\sigma) (1 - \cos 2\pi \sigma x) d\sigma \quad \dots (5)$$

となる。光路差 x を変えると、強度 $I(x)$ が変化する。この干渉波形はインターフェログラムと呼ばれ、得られたインターフェログラムをフーリエ変換すると、スペクトル $B(\sigma)$ が求められる。本発明のテラヘルツ分光光度計はこのようなフーリエ分光法にも基づくため、多くの周波数成分を同時に測定できる利点がある。

【0006】

【実施例】これまでに述べたTPG光源とMP型干渉計を組み合わせるにより、スペクトル強度の大きなテラヘルツ分光光度計が実現できる。MP型分光計の透過特性は請求項6記載のワイヤグリッドの反射透過特性に大きく依存する。前記ビームスプリッタとして使うワイヤグリッドはワイヤの間隔を g とすると $4g$ 以下の波長では効率が落ちる。本発明の請求項1記載のTPGによるTHz波波長は33 cm⁻¹~71 cm⁻¹(140 μm~310 μm)の帯域であるので、本発明の分光システムはまずこの領域を測定できるように、ワイヤ間隔 g (μm)が35 μm以下が必要である。前記ワイヤグリッドは、直径が10 μm、格子間隔がそれぞれ25 μmおよび30 μmのタングステン線より構成されたもので、格子面有効直径が90 mmである。請求項1のTPGより発生したTHz光源のビーム直径は約5 mm、広がり角度約1.5°、前記ビームスプリッタの位置ではビーム直径が約15 mmであるので、十分な有効面積を持つ。図6に本発明のテラヘルツ分光光度計のシステム構成を示す。THz波発生に用いた請求項1のTPG光源は、請求項2記載の近赤外のレーザーとしてNd:YAGレーザー(パルスエネルギー12 mJ、パルス幅7 ns)で励起し、発生したTHz波は請求項4記載のSiプリズムを用い空間に放射され、軸外し放物面鏡によりコリメートしたあとポラライザP₁で直線偏光にして、請求項6記載のMP型干渉計に導く。固定鏡M₁と可動鏡M₂に用いた反射鏡は直角プリズムを二枚組合わせた直角反射鏡を用いており、アルミニウムのコーティングを施している。これにより入射電磁波を常に入射方向に戻すことができるように調整されている。この反射光は入射光の偏波と直行する偏波を持つので、ビームスプリッタにより再び重ねられる。可動鏡を駆動させるアクチュエータは、最小移動間隔10 μm、最大移動距離20 cmである。干渉したTHz波の検出には請求項7記載の感度の高い4K-Siボロメータを使用した。

可動鏡を走査することにより得られる信号波形（インターフェログラム）をフーリエ変換することによって、スペクトル情報を得る。本発明のテラヘルツ分光光度計システムは機器制御用ソフトを用いて、可動鏡の走査および検出器の出力データの自動取り込みを行った。インターフェログラムの測定手順は、次の通りである。始めに、可動距離およびサンプリング間隔を入力し、分解能および波数の領域を決める。次にコンピュータから命令を送り、可動鏡をサンプリング開始位置 x_i まで動かし、鏡が x_i に着いた後、検出器からの出力をオシロスコープを通しコンピュータに取り込む。その後、再び可動鏡を次の位置 x_{i+1} まで動かした後、始めの可動鏡のサンプリング開始位置 x_i を x_{i+1} おきかえてその後の工程を必要回数繰り返してインターフェログラムを得る。以上の測定およびインターフェログラムのフーリエ変換はいずれもコンピュータ上で処理し、スペクトル情報を得ている。

【0007】

【発明の効果】以上説明したように、本発明のテラヘルツ分光光度計の測定例を示す。スペクトル測定の最大分解能を得るには、最大光路差が得られるように光路差0の位置を始点としてインターフェログラムを測定すれば良い。図7は大気中で測定したTHz波のインターフェログラムの一例である。本測定では、最大 100 cm^{-1} （3THz）付近までの測定を行うために、サンプリング間隔を $\Delta X = 40\text{ }\mu\text{m}$ （最大波数 125 cm^{-1} ）に設定した。また最大光路差は1cmに設定し、これに対応する分解能は 0.5 cm^{-1} （15GHz）である。図8はインターフェログラムのフーリエ変換により得られたスペクトルであり、全体の包絡線がTHz光源のスペクトル強度を与える。この前記TPGの中心波長は0.5～5THzの範囲で同調が可能である。

【0008】このように、従来光源のスペクトル強度が不足することがさげられなかった0.5～5THz帯での分光で、THz帯パラメトリック発生光を光源とした

MP型テラヘルツ分光光度計システムをもってして、THz波帯における高分解能な分光を可能たらしめる一技術となり得る。

【図面の簡単な説明】

【図1】ボラリトンの分散関係と位相整合曲線を表す図である。

【図2】THzパラメトリック発生実験の構成図である。

【図3】パラメトリック利得の周波数特性を示す図である。

【図4】マーチンパレット型干渉計の構成図である。

【図5】ワイヤグリッドの偏光特性を示す図である。

【図6】テラヘルツ分光光度計の全体の構成図である。

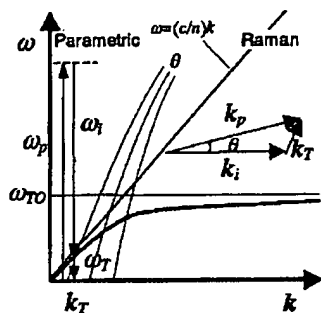
【図7】テラヘルツ分光光度計により大気中計測したTHz波のインターフェログラムの図である。

【図8】コンピュータによるフーリエ変換後のスペクトルを示す図である。

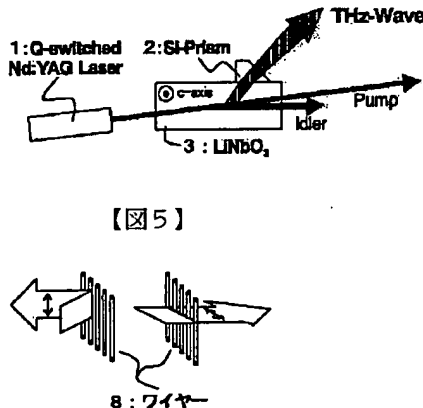
【符号の説明】

- 1 励起レーザー
- 2 結合器
- 3 非線形結晶
- 4 分配器
- 5 偏光版
- 6 固定鏡
- 7 稼動鏡
- 8 ワイヤー
- 9 コリメート用非対称球面ミラー
- 10 分光用資料
- 11 検出器
- 12 稼動鏡用コントローラー
- 13 オシロスコープ
- 14 システム制御用コンピューター
- 15 テラヘルツ分光光度計

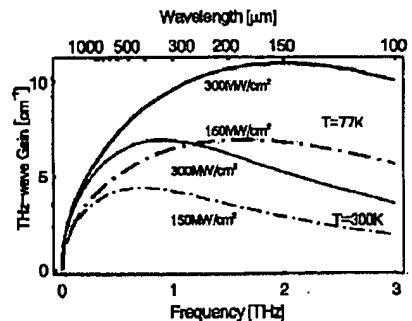
【図1】



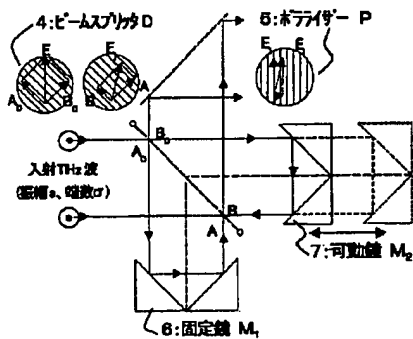
【図2】



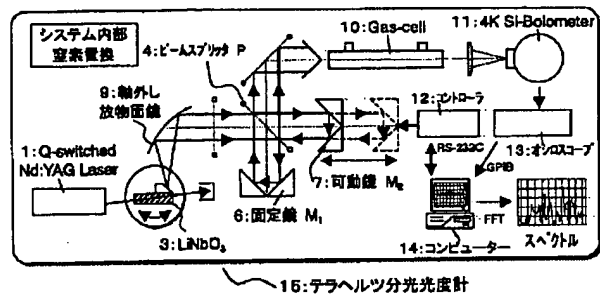
【図3】



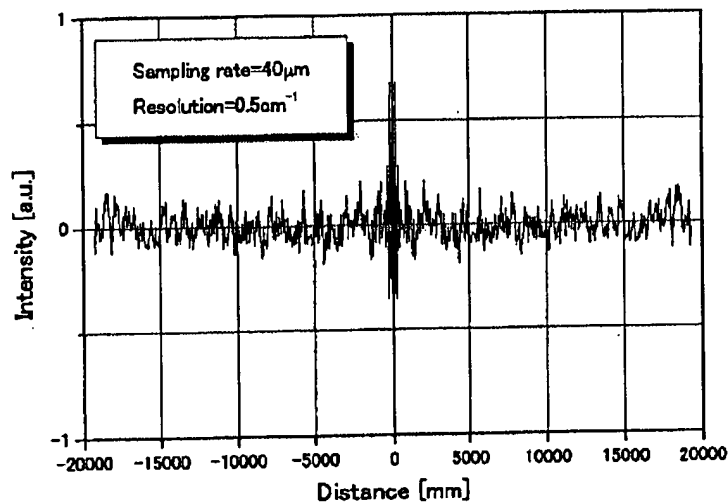
【図4】



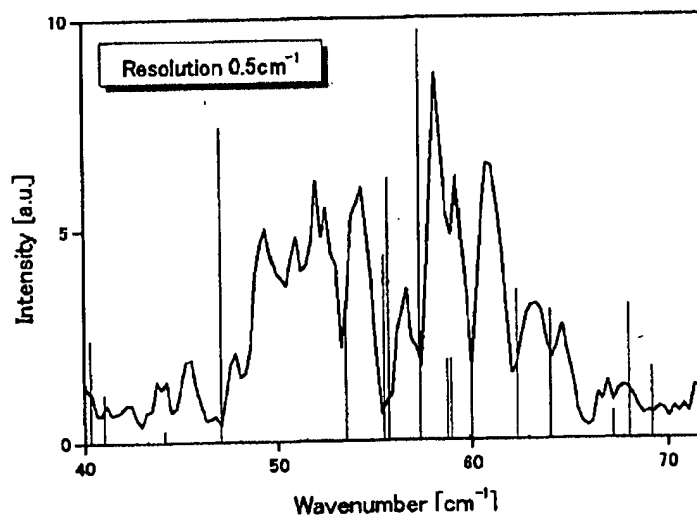
【図6】



【図7】



【図8】



PAT-NO: JP02000321134A
DOCUMENT-IDENTIFIER: JP 2000321134 A
TITLE: TERA HERTZ
SPECTROPHOTOMETER

PUBN-DATE: November 24, 2000

INVENTOR-INFORMATION:

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APPL-NO: JP11135199

APPL-DATE: May 17, 1999

INT-CL G01J003/10 , G01J003/26 ,
(IPC): G02F001/39

ABSTRACT:

PROBLEM TO BE SOLVED: To provide a spectrophotometer which can measure spectroscopy in THr(tera Hertz) region with good S/N by combining a variable wavelength tera Hertz wave light source having high spectral strength with a Type Fourier interferometer.

SOLUTION: The tera Hertz spectrometer 15 comprises a TPG(tera Hertz parametric generation) light source for radiating a THz wave generated by pumping a nonlinear crystal LiNbO₃ 3 through an Nd:YAG laser 1 into the space using an Si prism and collimating it through an off-axis parabolic mirror 9, an MP type interferometer for splitting

the **THz** wave through a beam splitter 4 into two light beams and causing interference by superposing them again by means of a fixed mirror M16 and a movable mirror M27, a gas cell 10 filled with a sample for spectroscopy, and a 4K-Si bolometer 11 for detecting **THz** wave.

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CLAIMS

[Claim(s)]

[Claim 1] The spectrometer characterized by using the wavelength adjustable terahertz wave (terahertz parametric-below generating: TPG and abbreviation) obtained according to parametric generating (PG) which is a nonlinear optical effect as the light source.

[Claim 2] The spectrometer characterized by making into the light source in a small and powerful far infrared region the terahertz (Following THz and abbreviation) wave generated by exciting by the near-infrared light source in claim 1, using LiNbO3 and LiTaO3 grade as nonlinear crystal.

[Claim 3] The spectrometer characterized by having the light source which can carry out adjustable [of the main wavelength of a THz wave produced from the inside of nonlinear crystal] in claim 2 by changing whenever [to the crystal of said excitation light source / incident angle].

[Claim 4] The spectrometer characterized by having the light source with the description to which outgoing radiation of the THz wave is carried out in the about 1 direction even if it changes whenever [to the crystal of the excitation light source / incident angle] in claim 2 by using the prism made from Si for the ejection to the inside of the atmospheric air of the THz wave from nonlinear crystal.

[Claim 5] The small high brightness terahertz spectrophotometer characterized by combining the spectroscopy using two beam interference with the wavelength adjustable TPG light source with strong spectral intensity.

[Claim 6] The spectrometer using the Martin-PAPURETTO mold fourier interferometer (a following MP mold interferometer and abbreviation) which used for the beam splitter the wire grid which has a transparency property with the sufficient effectiveness in a Submillimeter field in an interferometer in claim 5.

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DETAILED DESCRIPTION

[Detailed Description of the Invention]

[0001]

[The technical field to which invention belongs] This invention relates to the small high brightness terahertz spectrophotometer realized by combining the spectroscopy using two beam interference with the wavelength adjustable TPG light source with the strong spectral intensity obtained according to parametric generating which is a nonlinear optical effect.

[0002]

[Description of the Prior Art] The high-pressure mercury-vapor lamp which has a continuous frequency component conventionally is used for the spectrum of a far infrared region as the almost only light source, and the advantageous Fourier transform spectrometer (Following FTS and abbreviation) using two beam interference is widely used in respect of the deployment of the quantity of light as a spectrometer. This uses that interference light reinforcement supports the Fourier transform from the wave number space of a light source spectrum to real space. They are the lamellar mold which acquires the 2 flux of lights comparatively more, and Martin who acquires the 2 flux of lights using polarization by the Michelson mold from which an FTS class acquires the 2 flux of lights amplitude splitting by the approach of acquiring the 2 flux of lights although divided light into the 2 flux of lights from the light source by the beam splitter, it was made to interfere after making the optical path difference between the 2 flux of lights, and the spectrum has been obtained from the interference curve in FTS, and the wave front. - It is divided roughly into three sorts of a PAPURETTO mold. In order that the effectiveness of the semitransparent mirror of the submillimeter field Michelson mold FTS may fall in this, many MP mold interferometers with an efficient transparency property are used.

[0003]

[Problem(s) to be Solved by the Invention] With the conventional far infrared exterior division light, since the spectral intensity of the high-pressure mercury-vapor lamp which is the light source is low, there is a fault that an overall S/N ratio will fall [interferogram information], including a noise mostly. It aims at the ability to measure the spectrum in this THz field (0.5-5THz) with sufficient S/N.

[0004]

[Means for Solving the Problem] In order to solve the above-mentioned technical problem, the following terahertz spectrophotometers were used for this invention. namely, the wavelength adjustable obtained according to parametric generating according to claim 1 -- it is the small high brightness terahertz spectrophotometer realized by combining it with the spectroscopy using two beam interference as it is in claim 5, using TPG as the light source. TPG generated by exciting the nonlinear crystal LiNbO₃ according to claim 2 and LiTaO₃ grade by the near-infrared light source was used for the light source. Since this is wavelength adjustable, and is the pulse of nsec width of face in a large far infrared region and it has comparatively strong reinforcement, the long optical path length, and broadcloth spectral characteristics, it has the description advantageous to a spectrum and can serve as the light source in a small and powerful far infrared region. Furthermore, as a method of a spectrum, having considered the deployment of the quantity of light in a far infrared region, the fourier spectrometer using two beam interference was desirable, and the configuration of MP mold interferometer according to claim 6 which has a transparency property especially with the sufficient effectiveness in a Submillimeter field especially was used.

[0005]

[Embodiment of the Invention] Hereafter, the gestalt of this invention is explained with reference to a drawing. This invention is a small high brightness terahertz spectrophotometer realized by combining MP mold interferometer with the wavelength adjustable TPG light source, as indicated to claim 5. Here, each principle is shown.

A. In the generating principle light parametric interaction of THz wave parametric generating (TPG), when incidence of the pump wave (ω_P) ω_P is carried out to a nonlinear optical crystal according to claim 2, a signal wave (ω_S) and an idler (ω_I) are the phenomena generated according to law-of-conservation-of-energy $\omega_P = \omega_S + \omega_I$

$P = \omega_i T + \omega_i$, and it becomes possible by extending the frequency of signal wave $\omega_i T$ even to THz wave band to offer the light source with the broad spectrum suitable for a spectrum. When wavelength conversion of the light wave using a parametric interaction according to claim 1 performs THz wave generating, when the interaction of only a pure light wave is used, gain is small, and actuation of THz wave band is difficult. However, Raman active [, such as said LiNbO_3 , LiTaO_3 , etc.,] and infrared light -- if this activity non-linear optical material is used, a strong interaction can be started through the elementary excitation wave (PORARITON) of the matter. In a low energy field, as shown in drawing 1, if strong sufficient excitation light source according to claim 2 is used in order [photon] to act and carry out, PORARITON causes the induction scattering phenomenon through PORARITON, and the efficient outbreak of a THz wave ($\omega_i T$) is possible for it. The schematic diagram of the TPG experiment to drawing 2 is shown. When incidence of the pump light is carried out into a crystal, the quantum noise (thermal noise) generated at the incidence edge is amplified by crystal gain, and the light (idler light) which the frequency shifted from pump light is outputted. And a THz wave occurs in the place where pump light and idler light filled the law of conservation of energy ($\omega_i T = \omega_i + \omega_i T$) and a law of conservation of momentum ($k_P = k_i + k_T$). The THz wave to generate has a broad spectrum (about 15cm^{-1}) depending on a light-receiving angle, and can align main wavelength by changing the incident angle of a crystal. Drawing 3 is as a result of [of the gain at the time of exciting non dope LiNbO_3 crystal with the wavelength of 1.064 micrometers] count, and it turns out that it has high gain in an about 150-400-micrometer field. The property that a gain coefficient increases with the pump light reinforcement IP originates in gain being proportional to the square root of IP. Moreover, the property that a gain coefficient increases in a low-temperature field originates mainly in reduction of the absorption coefficient in THz wave band.

B. The configuration of MP mold interferometer of principle claim 6 publication of the Martin-PAPURETTO mold interferometer is shown in drawing 4. In said MP mold interferometer, the polarization division method which divides the polarization direction of incident light and builds the two flux of lights is used. A wire grid according to claim 6 reflects the electromagnetic wave of the parallel polarization direction to this the wire, and makes a vertical electromagnetic wave penetrate (drawing 5). That is, it has the description that it is possible to set reflective:transparency of an incidence electromagnetic wave to 1:1, and division of an efficient electromagnetic wave can be performed, by leaning said wire grid to 45 degrees to the polarization direction of an electromagnetic wave. The direction of polarization of the THz wave which carries out incidence is vertical to space. A THz wave is divided into 1:1 by the beam splitter D of said wire grid set at 45 degrees according to claim 6. It is reflected by a fixed mirror and the movable mirror and the polarization direction rotates the reflected light and 90 degrees of transmitted lights, respectively. The THz wave again combined by D is divided into a component vertical to a component parallel to this wire by Polarizer P (wire grid). The electric field which carry out incidence to said beam splitter are [formulas 1].

$$E_i = e_x \frac{a}{\sqrt{2}} \cos \omega t + e_y \frac{a}{\sqrt{2}} \cos \omega t \quad \cdots (1)$$

The electric field again combined by said beam splitter are [formulas 2].

$$E_j = e_x \frac{a}{\sqrt{2}} \cos(\omega t + \Delta_A) + e_y \frac{a}{\sqrt{2}} \cos(\omega t + \Delta_B) \quad \cdots (2)$$

The amplitude is as follows when outgoing radiation is carried out from a next door and said polarizer P.

[Formula 3]

$$|E| = \frac{a}{2} (\cos(\omega t + \Delta_A) - \cos(\omega t + \Delta_B)) \quad \cdots (3)$$

However, delta A and delta B are each phase change, and the reinforcement is [a formula 4].

$$I_P = \langle |E|^2 \rangle = \frac{a^2}{4} (1 - \cos \Delta) = \frac{I_0}{2} (1 - \cos \Delta) \quad \cdots (4)$$

It becomes. The optical path difference and sigma of $\Delta = 2\pi \sigma x$ and x are the wave numbers here. When the spectral intensity is set to B (sigma), full strength is [a formula 5] by finding the integral about all sigma.

$$I(x) = \frac{1}{2} \int_0^\infty B(\sigma) (1 - \cos 2\pi \sigma x) d\sigma \quad \cdots (5)$$

It becomes. If the optical path difference x is changed, on-the-strength I (x) will change. This interference wave form is called an interferogram, and if the Fourier transform of the obtained interferogram is carried out, Spectrum B (sigma) will be called for. Since the terahertz spectrophotometer of this invention is based also on such fourier transform spectroscopy, it has the advantage which can measure many frequency components simultaneously.

[0006]

[Example] By combining the TPG light source and MP mold interferometer which were described until now, a

terahertz spectrophotometer with big spectral intensity is realizable. It depends for the transparency property of MP mold spectrometer on the reflective transparency property of a wire grid according to claim 6 greatly. If the wire grid used as said beam splitter sets spacing of a wire to g , effectiveness will fall on the wavelength of $4g$ or less. since the THz wave wavelength by TPG of this invention according to claim 1 is the band of 33cm^{-1} - 71cm^{-1} (140 micrometers - 310 micrometers) -- the spectrum of this invention -- the wire spacing g of a system (micrometer) is required for 35 micrometers or less so that this field may be first carried out by measurement. The diameter consisted of tungsten wires 10 micrometers and whose lattice spacings are 25 micrometers and 30 micrometers, respectively, and the lattice plane effective diameter of said wire grid is 90mm. Since a beam diameter is about 15mm in the location of about 5mm, the breadth include angle of about 1.5 degrees, and said beam splitter, the beam diameter of the THz light source generated from TPG of claim 1 has sufficient effective area. The system configuration of the terahertz spectrophotometer of this invention is shown in drawing 6 . The TPG light source of claim 1 used for THz wave generating is excited as near-infrared laser according to claim 2 by Nd:YAG laser (pulse energy 12mJ, 7ns of pulse width), and the generated THz wave is emitted to space using Si prism according to claim 4, after collimating it in an off-axis-paraboloid mirror, it is made into the linearly polarized light with a polarizer P1, and it is led to MP mold interferometer according to claim 6. The reflecting mirror used for the fixed mirror M1 and the movable mirror M2 uses the right-angle reflecting mirror with which a set of two rectangular prisms were aligned, and has performed coating of aluminum. It is adjusted so that an incidence electromagnetic wave can always be returned in the direction of incidence by this. Since this reflected light has the polarization of incident light, and the polarization which goes direct, it piles up again by the beam splitter. The actuators which make a movable mirror drive are the minimum migration spacing of 10 micrometers, and the 20cm of the maximum travels. 4 K-Si bolometer with high sensibility according to claim 7 was used for detection of a THz wave in which it interfered. SU ** KUTORU information is acquired by carrying out the Fourier transform of the signal wave form (interferogram) acquired by scanning a movable mirror. The terahertz spectrophotometer system of this invention performed the scan of a movable mirror, and automatic incorporation of the output data of a detector using the software for appliance control. The measurement procedure of an interferogram is as follows. Introduction, movable distance, and a sampling period are inputted, and the field of resolution and the wave number is decided. Next, after it moves delivery and a movable mirror for a computer to an instruction to the sampling starting position x_i and a mirror arrives at x_i , an oscilloscope is downloaded for the output from a detector to a through computer. then, the sampling starting position x_i of the movable mirror begun after moving a movable mirror to the following location x_{i+1} again -- x_i -- it obtains in every one and a subsequent process is acquired for the count repeat interferogram of the need. Each of above measurement and Fourier transform of an interferogram was processed on the computer, and has acquired SU ** KUTORU information.

[0007]

[Effect of the Invention] As explained above, the example of measurement of the terahertz spectrophotometer of this invention is shown. the max of spectrum measurement -- what is necessary is just to measure an interferogram by making the location of the optical path difference 0 into the starting point so that the maximum optical path difference may be acquired in order to obtain resolution Drawing 7 is an example of the interferogram of the THz wave measured in atmospheric air. In this measurement, in order to perform measurement to the a maximum of 100cm^{-1} (3THz) neighborhood, the sampling period was set as $\Delta X = 40\text{micrometer}$ (number 125cm of maximum waves- 1). Moreover, the maximum optical path difference is set as 1cm, and the resolution corresponding to this is 0.5cm^{-1} (15GHz). Drawing 8 is the spectrum obtained by the Fourier transform of an interferogram, and the whole envelope gives the spectral intensity of the THz light source. Said this main wavelength of TPG can align in 0.5-5THz.

[0008] thus, a high resolution spectrum [in / THz band parametric generating light is carried out with MP mold terahertz spectrophotometer system made into the light source with the spectrum in the 0.5-5THz band by which it was not avoided that the spectral intensity of the light source runs short conventionally, and / THz wave band] -- possible ** -- it is -- it can become ** 1 technique.

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TECHNICAL FIELD

[The technical field to which invention belongs] This invention relates to the small high brightness terahertz spectrophotometer realized by combining the spectroscopy using two beam interference with the wavelength adjustable TPG light source with the strong spectral intensity obtained according to parametric generating which is a nonlinear optical effect.

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PRIOR ART

[Description of the Prior Art] The high-pressure mercury-vapor lamp which has a continuous frequency component conventionally is used for the spectrum of a far infrared region as the almost only light source, and the advantageous Fourier transform spectrometer (Following FTS and abbreviation) using two beam interference is widely used in respect of the deployment of the quantity of light as a spectrometer. This uses that interference light reinforcement supports the Fourier transform from the wave number space of a light source spectrum to real space. They are the lamellar mold which acquires the 2 flux of lights comparatively more, and Martin who acquires the 2 flux of lights using polarization by the Michelson mold from which an FTS class acquires the 2 flux of lights amplitude splitting by the approach of acquiring the 2 flux of lights although divided light into the 2 flux of lights from the light source by the beam splitter, it was made to interfere after making the optical path difference between the 2 flux of lights, and the spectrum has been obtained from the interference curve in FTS, and the wave front. - It is divided roughly into three sorts of a PAPURETTO mold. In order that the effectiveness of the semitransparent mirror of the submillimeter field Michelson mold FTS may fall in this, many MP mold interferometers with an efficient transparency property are used.

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EFFECT OF THE INVENTION

[Effect of the Invention] As explained above, the example of measurement of the terahertz spectrophotometer of this invention is shown. the max of spectrum measurement -- what is necessary is just to measure an interferogram by making the location of the optical path difference 0 into the starting point so that the maximum optical path difference may be acquired in order to obtain resolution Drawing 7 is an example of the interferogram of the THz wave measured in atmospheric air. In this measurement, in order to perform measurement to the a maximum of 100cm⁻¹ (3THz) neighborhood, the sampling period was set as $\Delta X = 40 \mu\text{m}$ (number 125cm of maximum waves- 1). Moreover, the maximum optical path difference is set as 1cm, and the resolution corresponding to this is 0.5cm⁻¹ (15GHz). Drawing 8 R> 8 is the spectrum obtained by the Fourier transform of an interferogram, and the whole envelope gives the spectral intensity of the THz light source. Said this main wavelength of TPG can align in 0.5-5THz. [0008] thus, a high resolution spectrum [in / THz band parametric generating light is carried out with MP mold terahertz spectrophotometer system made into the light source with the spectrum in the 0.5-5THz band by which it was not avoided that the spectral intensity of the light source runs short conventionally, and / THz wave band] -- possible ** -- it is -- it can become ** 1 technique.

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TECHNICAL PROBLEM

[Problem(s) to be Solved by the Invention] With the conventional far infrared exterior division light, since the spectral intensity of the high-pressure mercury-vapor lamp which is the light source is low, there is a fault that an overall S/N ratio will fall [interferogram information], including a noise mostly. It aims at the ability to measure the spectrum in this THz field (0.5-5THz) with sufficient S/N.

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MEANS

[Means for Solving the Problem] In order to solve the above-mentioned technical problem, the following terahertz spectrophotometers were used for this invention. namely, the wavelength adjustable obtained according to parametric generating according to claim 1 -- it is the small high brightness terahertz spectrophotometer realized by combining it with the spectroscopy using two beam interference as it is in claim 5, using TPG as the light source. TPG generated by exciting the nonlinear crystal LiNbO₃ according to claim 2 and LiTaO₃ grade by the near-infrared light source was used for the light source. Since this is wavelength adjustable, and is the pulse of nsec width of face in a large far infrared region and it has comparatively strong reinforcement, the long optical path length, and broadcloth spectral characteristics, it has the description advantageous to a spectrum and can serve as the light source in a small and powerful far infrared region. Furthermore, as a method of a spectrum, having considered the deployment of the quantity of light in a far infrared region, the fourier spectrometer using two beam interference was desirable, and the configuration of MP mold interferometer according to claim 6 which has a transparency property especially with the sufficient effectiveness in a Submillimeter field especially was used.

[0005]

[Embodiment of the Invention] Hereafter, the gestalt of this invention is explained with reference to a drawing. This invention is a small high brightness terahertz spectrophotometer realized by combining MP mold interferometer with the wavelength adjustable TPG light source, as indicated to claim 5. Here, each principle is shown.

A. In the generating principle light parametric interaction of THz wave parametric generating (TPG), when incidence of the pump wave (ω_P) ω_P is carried out to a nonlinear optical crystal according to claim 2, a signal wave (ω_T) and an idler (ω_i) are the phenomena generated according to law-of-conservation-of-energy $\omega_P = \omega_T + \omega_i$, and it becomes possible by extending the frequency of signal wave ω_T even to THz wave band to offer the light source with the broad spectrum suitable for a spectrum. When wavelength conversion of the light wave using a parametric interaction according to claim 1 performs THz wave generating, when the interaction of only a pure light wave is used, gain is small, and actuation of THz wave band is difficult. however, Raman active [, such as said LiNbO₃, LiTaO₃, etc.,] and infrared light -- if this activity non-linear optical material is used, a strong interaction can be started through the elementary excitation wave (PORARITON) of the matter. In a low energy field, as shown in drawing 1, if strong sufficient excitation light source according to claim 2 is used in order [photon] to act and carry out, PORARITON causes the induction scattering phenomenon through PORARITON, and the efficient outbreak of a THz wave (ω_T) is possible for it. The schematic diagram of the TPG experiment to drawing 2 is shown. When incidence of the pump light is carried out into a crystal, the quantum noise (thermal noise) generated at the incidence edge is amplified by crystal gain, and the light (idler light) which the frequency shifted from pump light is outputted. And a THz wave occurs in the place where pump light and idler light filled the law of conservation of energy ($\omega_P = \omega_i + \omega_T$) and a law of conservation of momentum ($k_P = k_i + k_T$). The THz wave to generate has a broad spectrum (about 15cm- 1) depending on a light-receiving angle, and can align main wavelength by changing the incident angle of a crystal. Drawing 3 is as a result of [of the gain at the time of exciting non dope LiNbO₃ crystal with the wavelength of 1.064 micrometers] count, and it turns out that it has high gain in an about 150-400-micrometer field. The property that a gain coefficient increases with the pump light reinforcement IP originates in gain being proportional to the square root of IP. Moreover, the property that a gain coefficient increases in a low-temperature field originates mainly in reduction of the absorption coefficient in THz wave band.

B. The configuration of MP mold interferometer of principle claim 6 publication of the Martin-PAPURETTO mold interferometer is shown in drawing 4. In said MP mold interferometer, the polarization division method which divides the polarization direction of incident light and builds the two flux of lights is used. A wire grid according to claim 6 reflects the electromagnetic wave of the parallel polarization direction to this the wire, and makes a vertical electromagnetic wave penetrate (drawing 5). That is, it has the description that it is possible to set reflective:transparency of an incidence electromagnetic wave to 1:1, and division of an efficient electromagnetic wave

can be performed, by leaning said wire grid to 45 degrees to the polarization direction of an electromagnetic wave. The direction of polarization of the THz wave which carries out incidence is vertical to space. A THz wave is divided into 1:1 by the beam splitter D of said wire grid set at 45 degrees according to claim 6. It is reflected by a fixed mirror and the movable mirror and the polarization direction rotates the reflected light and 90 degrees of transmitted lights, respectively. The THz wave again combined by D is divided into a component vertical to a component parallel to this wire by Polarizer P (wire grid). The electric field which carry out incidence to said beam splitter are [formulas 1].

$$E_i = e_x \frac{a}{\sqrt{2}} \cos \omega t + e_y \frac{a}{\sqrt{2}} \cos \omega t \quad \dots (1)$$

The electric field again combined by said beam splitter are [formulas 2].

$$E_j = e_x \frac{a}{\sqrt{2}} \cos(\omega t + \Delta_A) + e_y \frac{a}{\sqrt{2}} \cos(\omega t + \Delta_B) \quad \dots (2)$$

The amplitude is as follows when outgoing radiation is carried out from a next door and said polarizer P.

[Formula 3]

$$I_D = 0.000005$$

However, delta A and delta B are each phase change, and the reinforcement is [a formula 4].

$$I_P = \langle |E|^2 \rangle = \frac{a^2}{4} (1 - \cos \Delta) = \frac{I_0}{2} (1 - \cos \Delta) \quad \dots (4)$$

It becomes. The optical path difference and sigma of delta=2pisigmax and x are the wave numbers here. When the spectral intensity is set to B (sigma), full strength is [a formula 5] by finding the integral about all sigma.

$$I(x) = \frac{1}{2} \int_0^\infty B(\sigma) (1 - \cos 2\pi x \sigma) d\sigma \quad \dots (5)$$

It becomes. If the optical path difference x is changed, on-the-strength I (x) will change. This interference wave form is called an interferogram, and if the Fourier transform of the obtained interferogram is carried out, Spectrum B (sigma) will be called for. Since the terahertz spectrophotometer of this invention is based also on such fourier transform spectroscopy, it has the advantage which can measure many frequency components simultaneously.

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EXAMPLE

[Example] By combining the TPG light source and MP mold interferometer which were described until now, a terahertz spectrophotometer with big spectral intensity is realizable. It depends for the transparency property of MP mold spectrometer on the reflective transparency property of a wire grid according to claim 6 greatly. If the wire grid used as said beam splitter sets spacing of a wire to g , effectiveness will fall on the wavelength of $4g$ or less. since the THz wave wavelength by TPG of this invention according to claim 1 is the band of 33cm^{-1} - 71cm^{-1} (140 micrometers - 310 micrometers) -- the spectrum of this invention -- the wire spacing g of a system (micrometer) is required for 35 micrometers or less so that this field may be first carried out by measurement. The diameter consisted of tungsten wires 10 micrometers and whose lattice spacings are 25 micrometers and 30 micrometers, respectively, and the lattice plane effective diameter of said wire grid is 90mm. Since a beam diameter is about 15mm in the location of about 5mm, the breadth include angle of about 1.5 degrees, and said beam splitter, the beam diameter of the THz light source generated from TPG of claim 1 has sufficient effective area. The system configuration of the terahertz spectrophotometer of this invention is shown in drawing 6 . The TPG light source of claim 1 used for THz wave generating is excited as near-infrared laser according to claim 2 by Nd:YAG laser (pulse energy 12mJ, 7ns of pulse width), and the generated THz wave is emitted to space using Si prism according to claim 4, after collimating it in an off-axis-paraboloid mirror, it is made into the linearly polarized light with a polarizer P1, and it is led to MP mold interferometer according to claim 6. The reflecting mirror used for the fixed mirror M1 and the movable mirror M2 uses the right-angle reflecting mirror with which a set of two rectangular prisms were aligned, and has performed coating of aluminum. It is adjusted so that an incidence electromagnetic wave can always be returned in the direction of incidence by this. Since this reflected light has the polarization of incident light, and the polarization which goes direct, it piles up again by the beam splitter. The actuators which make a movable mirror drive are the minimum migration spacing of 10 micrometers, and the 20cm of the maximum travels. 4 K-Si bolometer with high sensibility according to claim 7 was used for detection of a THz wave in which it interfered. SU ** KUTORU information is acquired by carrying out the Fourier transform of the signal wave form (interferogram) acquired by scanning a movable mirror. The terahertz spectrophotometer system of this invention performed the scan of a movable mirror, and automatic incorporation of the output data of a detector using the software for appliance control. The measurement procedure of an interferogram is as follows. Introduction, movable distance, and a sampling period are inputted, and the field of resolution and the wave number is decided. Next, after it moves delivery and a movable mirror for a computer to an instruction to the sampling starting position x_i and a mirror arrives at x_i , an oscilloscope is downloaded for the output from a detector to a through computer. then, the sampling starting position x_i of the movable mirror begun after moving a movable mirror to the following location x_{i+1} again -- x_i+ -- it obtains in every one and a subsequent process is acquired for the count repeat interferogram of the need. Each of above measurement and Fourier transform of an interferogram was processed on the computer, and has acquired SU ** KUTORU information.

[Translation done.]

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DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]

[Drawing 1] It is drawing showing the dispersion relation and the phase matching curve of PORARITON.

[Drawing 2] It is the block diagram of a THz parametric generating experiment.

[Drawing 3] It is drawing showing the frequency characteristics of parametric gain.

[Drawing 4] It is the block diagram of the Martin-PAPURETTO mold interferometer.

[Drawing 5] It is drawing showing the polarization property of a wire grid.

[Drawing 6] It is the block diagram of the whole terahertz spectrophotometer.

[Drawing 7] It is drawing of the interferogram of the THz wave measured among atmospheric air with the terahertz spectrophotometer.

[Drawing 8] It is drawing showing the spectrum after the Fourier transform by the computer.

[Description of Notations]

1 Excitation Laser

2 Coupler

3 Nonlinear Crystal

4 Distributor

5 The Polarization Version

6 Fixed Mirror

7 Operation Mirror

8 Wire

9 Unsymmetrical Spherical-Surface Mirror for Collimation

10 Spectrum -- ** Data

11 Detector

12 Controller for Operation Mirrors

13 Oscilloscope

14 Computer for System Controls

15 Terahertz Spectrophotometer

[Translation done.]

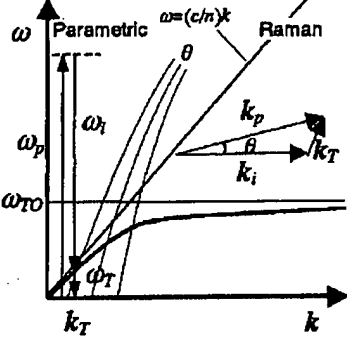
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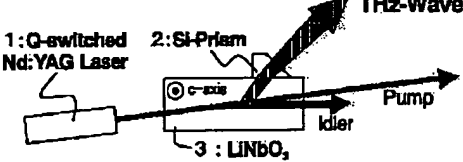
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DRAWINGS

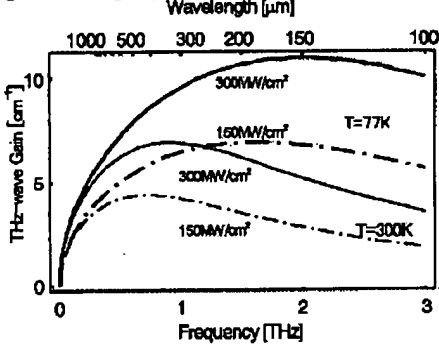
[Drawing 1]



[Drawing 2]



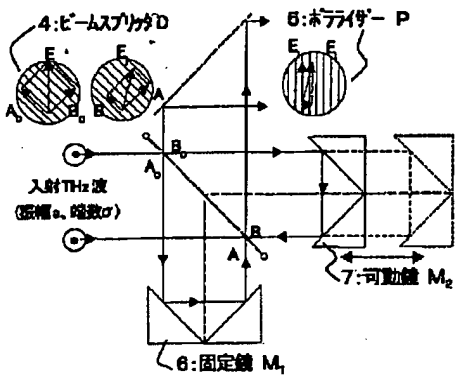
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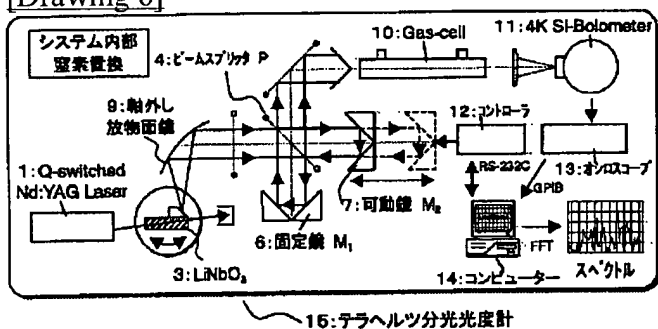
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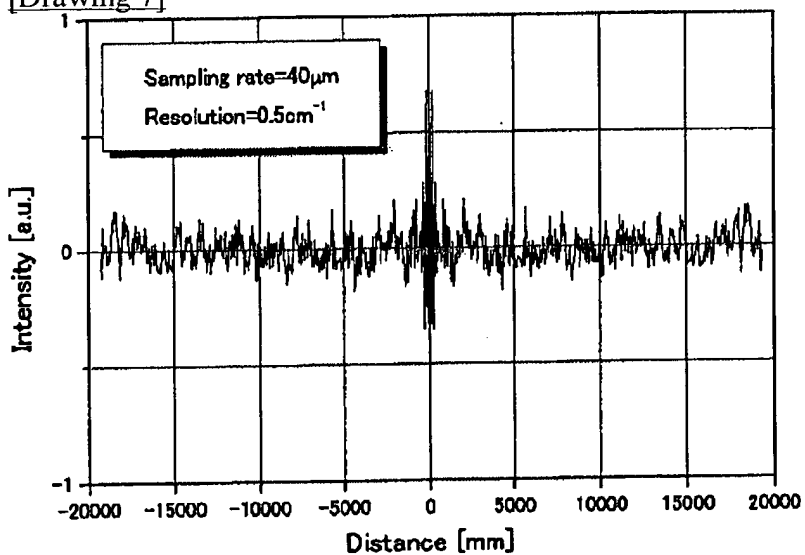
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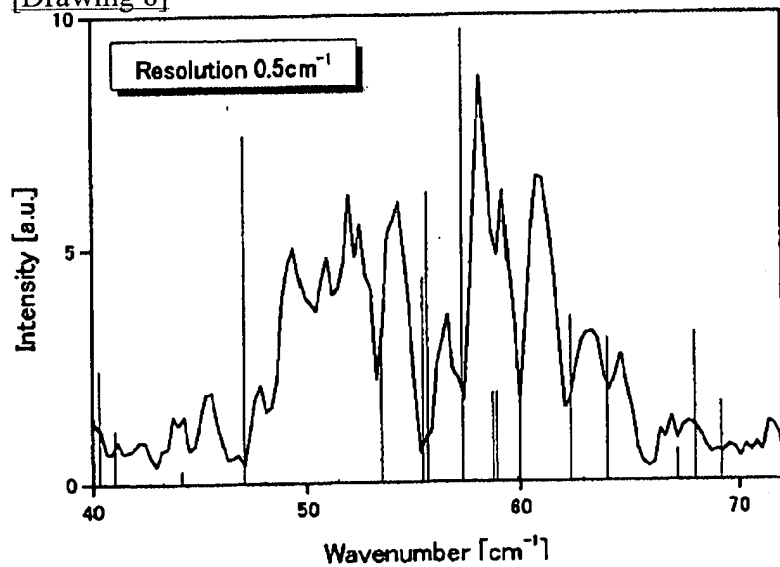
[Drawing 6]



[Drawing 7]



[Drawing 8]



[Translation done.]

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